Nihan & Terrey

A study of electric welding

Electrical Engineering

B. S.

1910

A STUDY OF ELECTRIC WELDING

BY

ROBERT EDWARD JOSEPH NIHAN

AND

WILLIAM HOMER TERREY

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

ELECTRICAL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE 1910

UNIVERSITY OF ILLINOIS

June 1 1910

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ROBERT EDWARD JOSEPH NIHAN and WILLIAM HOMER TERREY

ENTITLED A STUDY OF ELECTRIC WELDING

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

F. G. Willson
Instructor in Charge

APPROVED: Ernst Berg

HEAD OF DEPARTMENT OF ELECTRICAL ENGINEERING

T A B L E   O F   C O N T E N T S

T E S T S

T A B L E   O F   C O N T E N T S - Cont.

I N T R O D U C T I O N

This investigation consists of a study of the methods of electric welding, the machines used, and of their applications, from a commercial standpoint, and some data compiled from actual tests on welds made from small stock. A study of the most important machines used for welding in the commercial world, was made from current literature, and tables to show the comparative costs of electrical methods with other methods are introduced. The actual tests were made on small specimens on a machine designed to weld by use of the resistance method. Data was obtained of power used in making the welds and testing them for tensile strength and efficiency.

D E F I N I T I O N

Welding is the process of uniting two or more pieces of metal into a homogeneous body, by heating the parts to be united to a temperature that will produce fusion of the adjacent molecules. When the heating effects of an electric current is applied to produce the required temperature for fusion, the process is called electric welding.

H I S T O R I C A L

The art of welding iron is probably as old as the earliest production of that metal; in fact iron was the only weldable metal, with the exception of gold and platinum, until the closing years of the nineteenth century. When the heating effects of the electric current were applied to weld metals, it was found that many alloys could be welded by this process, which otherwise could not be done. However, at the present time, iron is the principal metal that is welded by electricity.

During recent years the extension of electric welding has been steady, and each year has witnessed its entrance into new fields. The rapidity, cleanliness, accuracy, and economy of the electric process has won for it an important place in the manufacturing world. The uniformity of work, extreme localization of heat to the parts to be united, and the fact that the process is not limited to iron and steel, but can also be applied to copper, brass, bronzes, and lead, are characteristics of electric welding.

METHODS OF ELECTRIC WELDING.

There are two separate processes by which the heating effects of an electric current are utilized for welding metals; namely, the Resistance method, and the Arc method. A discussion of the resistance method, with applications of the same, will now be given.

When an electric current passes through a circuit, the temperature of the material in the circuit is increased to a value depending upon the resistance of the material and the strength of the current. The electric power transferred into heat is equal to I^2R, in which I is the current in amperes, and R is the resistance of the circuit in ohms. Since the resistance of iron is comparatively low, especially for a very short length of the material, it is necessary to pass a very large current through the material in order to bring it to a welding heat. This large current is produced by means of a transformer which steps down the voltage. Since the product of volts and amperes in the primary and secondary coils of the transformer is approximately the same, then the current at a low voltage will be very large, when stepped down from a higher voltage. In its simplest form, an electric welder consists of a transformer, the primary coil of which receives current at any commercial voltage, and steps it down to current at a voltage sufficient to send the necessary amperage through the secondary. Its secondary coil consists of a few turns of copper bar of very large cross-section so that it may carry a large current. The low voltage impressed upon the pieces to be welded is easily insulated, and cannot in any way endanger the operator. The pieces to be welded are held in clamps or vises carrying the terminals of the

secondary coil. The clamping devices and the switch may be either of hand control or automatic, as is done in many machines.

APPLICATIONS OF THE RESISTANCE METHOD OF ELECTRIC WELDING

Electric welding by the resistance method is used in many manufacturing establishments at the present time. In the wagon and carriage industry the process is applied in the production of steel tires of all cross-sections, axles, fifth wheels, and shaft iron. The wires inclosed in rubber tires for holding them in place are also welded in many cases by an electric current. In the manufacture of bicycles, various parts, such as crank-hangers, pedals, frames, and brake parts are welded by this process. Crank shafts for automobile engines are formed by welding the separate parts together, and afterwards lightly machining and finishing the approximately correct shaft. This application of electric welding has become especially important in the last few years because of the increased demand for automobiles. Elaborate machinery for the production of steel tubing from flat stock by the progressive welding of a longitudinal seam has been put into operation. Tubes or shells up to sixteen inches in diameter have been made from sheet metal in this manner.

In the simpler types of electric welding machines, especially where the machines are designed to do a variety of work, perhaps of different forms or sizes of pieces, the adjustments are usually made by hand. In many cases, as when welding wire, the pressure is automatically applied, and the current is cut off automatically

upon the completion of the joint. In more automatic machines, adapted for rapid repetition of the same operation on identical pieces, the machine runs continuously, being driven by a source of power. Examples of such machines are found in the manufacture of wire fence, and the consecutive welding of the links of chains. In these machines, the operation once started goes on continuously, as long as the supply of material lasts.

Another important application of electric welding is that of rail bonding. An equipment designed by Johnson for such work, has been found very satisfactory and is used quite extensively at the present. Below is given a sketch, showing the necessary apparatus to perform this work.

The apparatus shown below is mounted on three cars; car number 1 contains a booster; car number 2 a rotary converter; and car number 3 the welding transformer. The transformer is mounted upon a carriage, swung from a heavy crane, arranged to be raised or lowered, or swung from side to side. The secondary coil is designed to deliver a current of from 30,000 to 40,000 amperes at a voltage of from two to four volts. The transformer is air-cooled and the contact blocks forming the jaws of the welder are made hollow to permit the circulation of water for cooling purposes

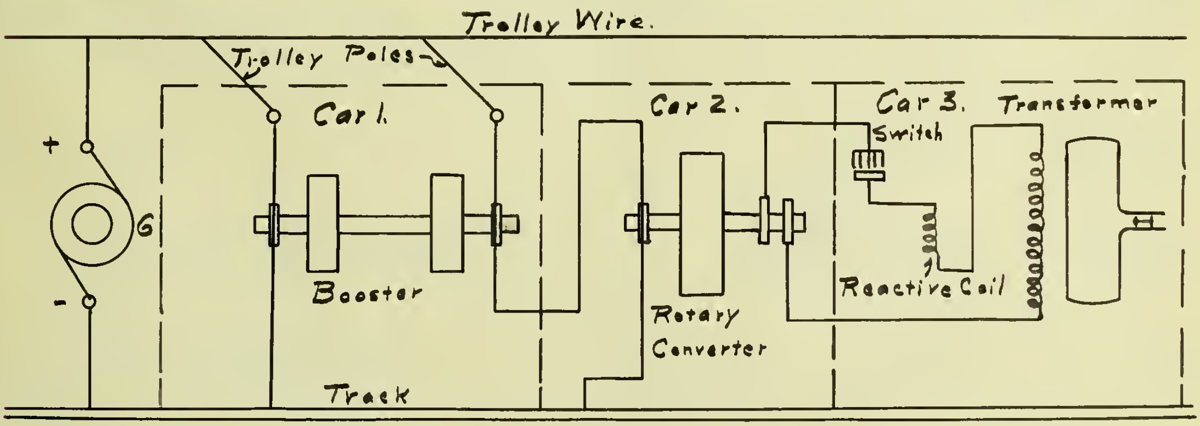

Figure 1.

TABLE 1.

COST OF MAKING 9/32 INCH COMMON CHAIN.

COMPILED BY ANDRIS-JOCHAMS, BRUSSELS, BELGIUM.

	On Gas Fire	By Electric Process
Daily average welded, in links	2800	4000
Daily average welded, in feet	233	333
Daily average welded, in pounds	175	263
Cost of material, 175 pounds, at $1.60 per 100 lbs.	$2.80	
Cost of material, 263 pounds at $1.60 per 100 lbs.		$4.208
Waste in winding, cutting, and welding	.28	0.0
Cost of welding at $1.65 per 100 pounds	$2.89	
Cost of welding at $1.50 per day for labor		$1.50
Cost of fuel, 3000 feet of gas at 15¢ per 1000 feet	.45	
Cost of current, 40,000 watt hours, at 5¢ per 1000		2.00
Daily expense (50 percent of welding cost)	1.45	.75
Total	$7.87	$8.458
Cost per 100 pounds	$4.50	$3.21
Cost per 100 feet	$3.87	$2.54

Mr. Andris-Jochams of Brussels, Belgium has had tables of data compiled from tests made, showing the relative costs of making 9/32 inch chain on a gas fire and a Girand Electric Welding Machine. The results, on page 5, show that the total cost of making chains on the Girand machine is $2.54 per one hundred feet as compared with $3.87 on a gas fire. Thus a saving of $1.33 per one hundred feet of chain of this size is accomplished by the use of electric welding.

ARC METHOD OF ELECTRIC WELDING

The second process of uniting metals by electricity depends upon the heating effects of the electric arc. There are two methods of arc welding; welding with a common arc flame, and with a deflected arc flame.

The common arc system is the more simple of the two. The pieces to be united are placed close together and used as one electrode of the arc while carbon is used as the other electrode, or in some cases, carbon is used as one electrode and some metal which is to be used as a joining material is used as the other electrode. In the first case, the molecules of the pieces to be welded are fused together while in the second case the joining material is fused and poured in between the pieces to be united, thereby casting or brazing the pieces together.

The deflected arc system is otherwise known as the Zerener system of arc welding, and its action is based upon the well known phenomenon of the deflection of the electric arc by a magnet.

The mutual action of an electric current and a magnet is the basis of the operation of dynamos, galvanometers, and most forms of electrical apparatus, but the effect is no where so strikingly shown as when an electro-magnet is placed in close proximity to an arc which is playing between two carbon points. In its application to arc welding, the magnet is used to drive the arc out from the electrodes till it resembles a blow-pipe flame, and the arc is used as such with the difference that its temperature is much higher.

There are two forms of apparatus for applying the deflected arc, according to the size of the flame required. Figure 2 shows the smaller form of apparatus. The arc passes from carbon to carbon and the feed is controlled by means of a small thumb screw. The horse-shoe magnet, the position of which is adjustable, deflects the arc and spreads the flame over the area desired to be heated. This form of apparatus is for general use and is applied by hand to the work by the operator.

The apparatus shown in Figure 3 is more ponderous, being used for larger and more specific kinds of work, and is suspended in any suitable position for the work in hand. The application and action of this apparatus is precisely the same as the smaller one, except that the carbons are fed automatically.

These machines have been successfully applied to such work as welding steel pipes longitudinally up to one-half inch thickness, boiler plates, deck plates, seams in barrels, and general welding around locomotive shops.

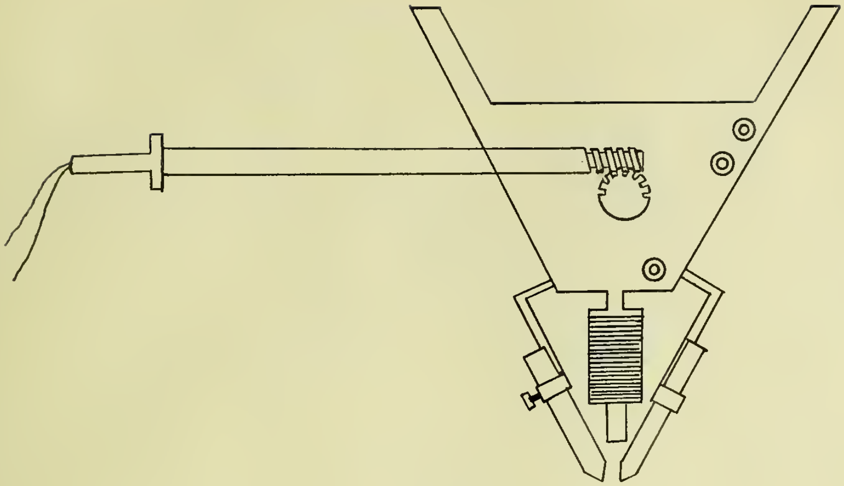

Figure 2

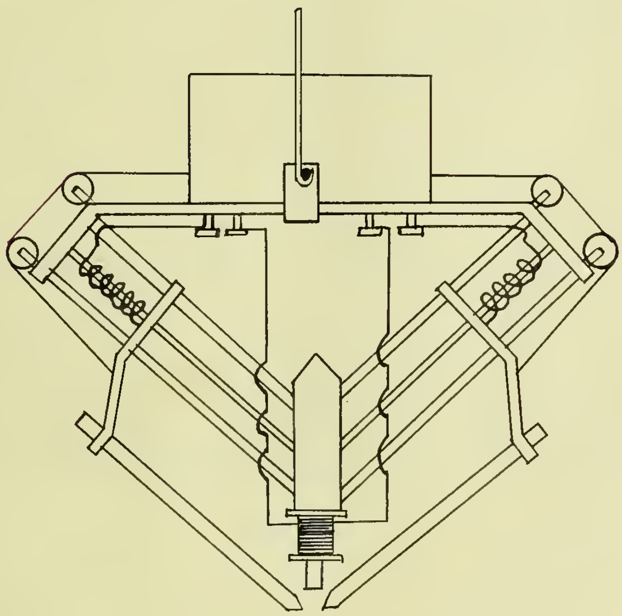

Figure 3

ADVANTAGES OF ELECTRIC WELDING

The process of making welds by applying an electric current to produce the required heat has many advantages over the process of heating the metal to be welded in a forge. Iron heated in a forge is heated from the exterior inwardly; consequently the outer surface reaches a welding heat first. It is often the case that when the appearance of the metal would indicate that the proper temperature had been reached, it is in reality heated insufficiently in the interior, so that when a weld is attempted it will stick together on the edges. In electric welding, on the other hand, the heat is developed first in the interior, and comes outward so that when the usual white sparks are emitted, it is known that the entire joint is heated to the welding point. The heated portion of the metal will not oxidize as much as in the fire welding process; hence a more perfect weld is formed. The art of forcing the abutting ends together in electric welding is very simple, and a weld is quickly made. There is no noise, dirt, or intense heat to contend with in the electric process, and no waste due to overheated or imperfect welds, and no dependence upon skilled or expensive labor.

APPARATUS FOR MAKING WELDS

In this investigation, the welds were made by the resistance method. The machine used was designed and constructed by James William Shaw and was used by him for a thesis on the "Methods of Welding Metals", for the degree of Bachelor of Science at the University of Illinois.

This machine consists of two cast iron jaws A and B in Fig. 5, mounted on a lathe bed. The fixed jaw A is in two parts, which are insulated from each other by fiber board F. The bottom part C is of cast iron and the upper part of brass. The sliding jaw B is also divided into two parts, the lower part being of cast iron is fixed to the frame, while the upper part h, which is of cast iron with a brass plate for contact piece, moves in the dove tail groove of the lower part. These jaws allow of adjustment to bring the specimens into line.

The test pieces are placed in grooves in the top of the brass plates and are held in place by clamps k, l, which are tightened on the pieces by set screws and nuts m, n. When the pieces are placed in position for a weld, the moving jaw is at its extreme lateral position, and its motion is effected by the lever i, and toggle joint j, and by application of hand power to the lever, pressure is brought to bear on the ends of the specimens when welding.

The transformer used was also designed and constructed by James William Shaw. It is of the shell type, having 168 turns of number 14 double cotton covered magnet wire on the primary, and three turns of number 0000 cable on the secondary, and is immersed in oil in a case to prevent overheating.

The core loss of the transformer, using 110 volts in the primary is 23.5 watts, magnetizing current .47 amperes, and using 220 volts in the primary the core loss is 71.5 watts and the magnetizing current .97 amperes. The resistance of the primary is .787 ohms.

The wattmeter used is of the Westinghouse portable integrating

type and was calibrated to read in watt minutes. This instrument has two sets of voltage terminals, one for 110 volts and the other for 220 volts, and also has a system of plugs in the current coil, by the combinations of which power is measured correctly up to a current of forty amperes.

The ammeter used is of the Weston type and reads from 0 to 50 amperes. The voltmeter used is also of this type and reads from 0 to 250 volts.

Referring to the diagram of connections in Figure 4, the power is received from the mains through the switch S, passes through the ammeter A, and wattmeter W, directly to the primary leads 1, 1, of the transformer and from the secondary leads 1^1, 1^1, to the brass contact pieces o, p, on the jaws of the welding machine.

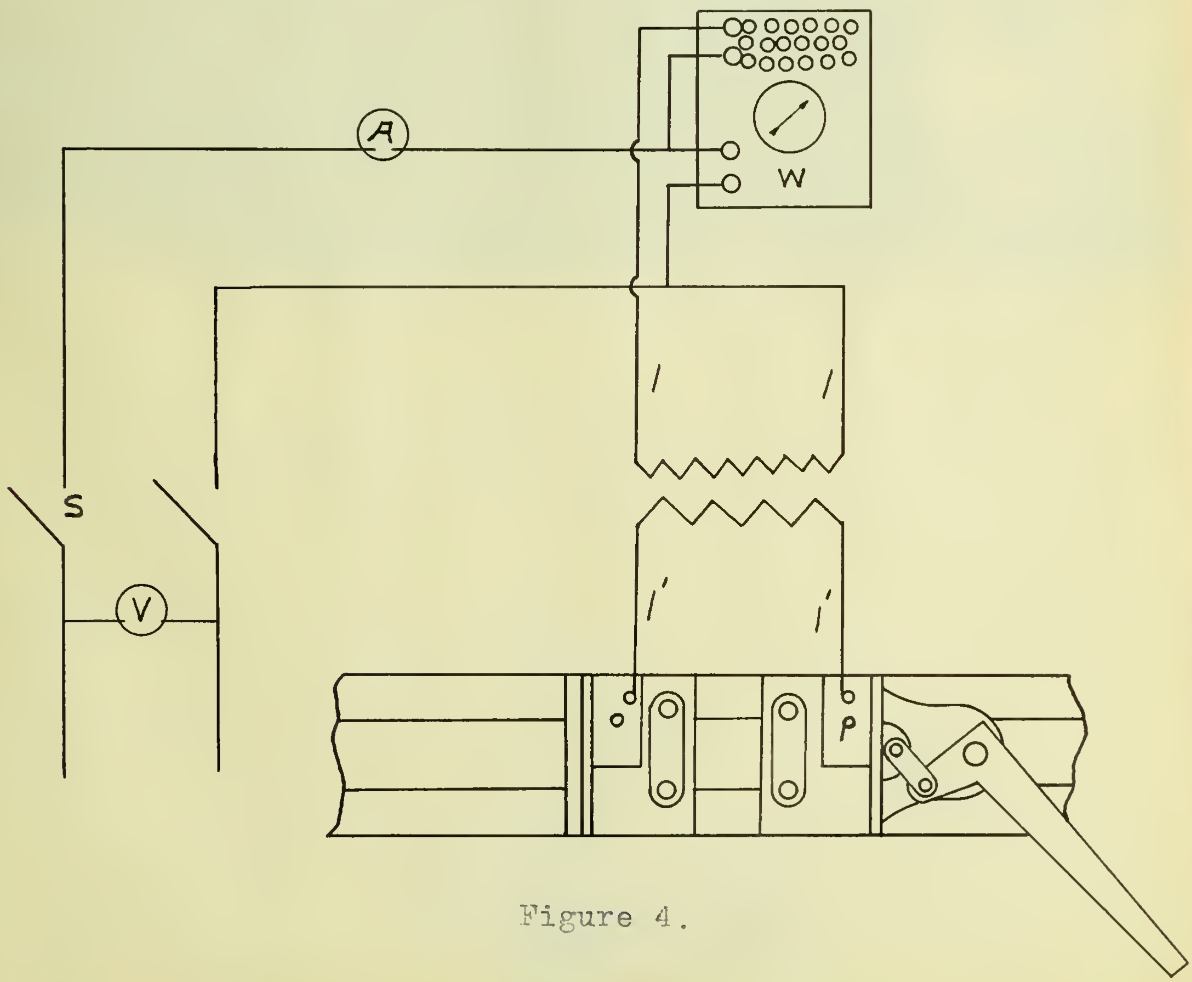

Figure 4.

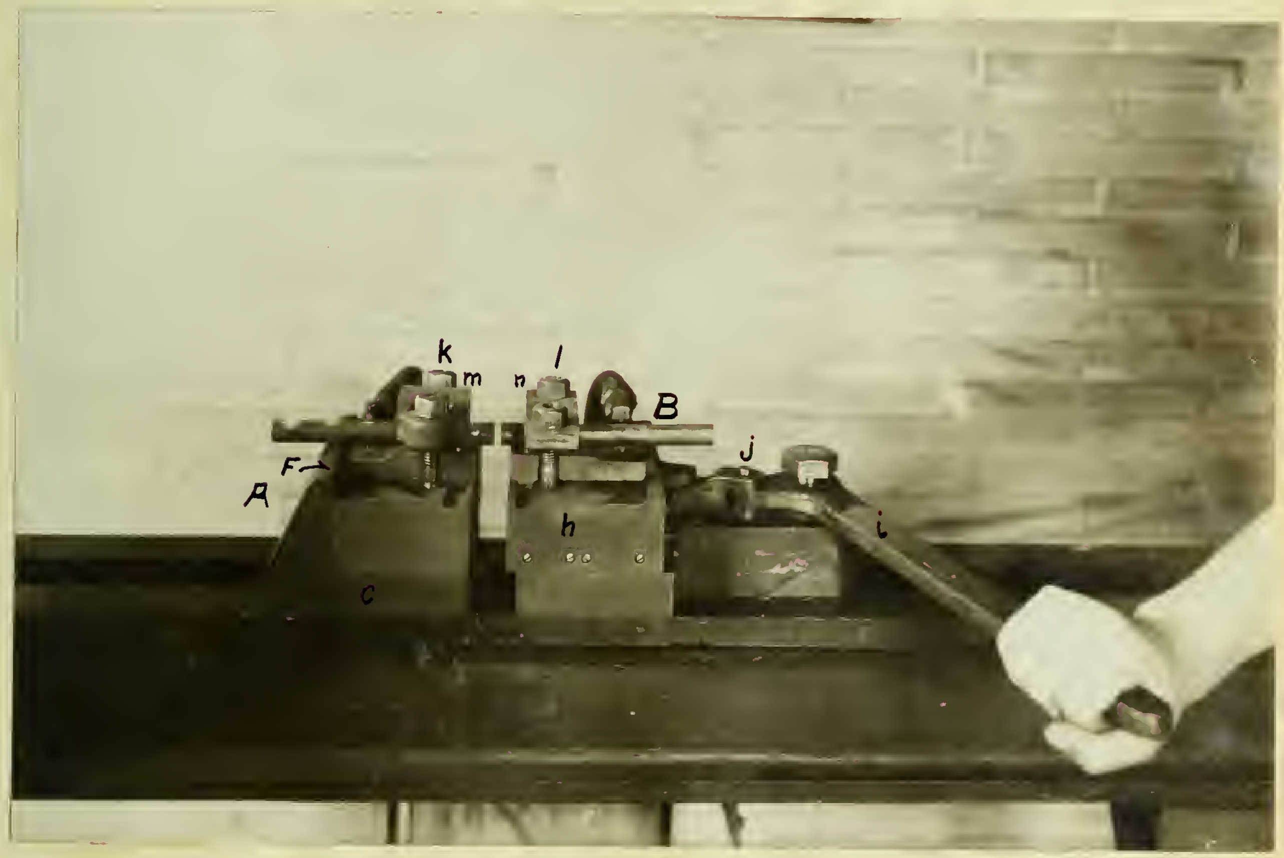

Figure 5.

PROCESS OF MAKING WELDS

The process of making welds with the machine used in these experiments is as follows: Bar iron was obtained and cut into test pieces six inches long; this length being convenient for the welding machine. Two of these test pieces were clamped in the jaws of the welder so that their ends were about 1/8 of an inch apart; care was taken in lining up the specimens. The primary circuit was then closed, followed immediately by the operation of bringing the two ends of the test pieces together. This operation closes the secondary circuit and allows current to flow through the test pieces. Pressure was exerted upon the pieces as desired, the more pressure causing more current to flow because of the decrease of resistance in the air gap. As soon as the metal reached its fusion point, the primary circuit was broken, at the same time a slightly greater pressure was exerted on the lever to force out the burned metal from the center of the weld. Sizes of stock up to and including one-half inch in diameter were welded in this manner. Also welds were made from square stock of 1/4 inch, 3/4 inch, and 7/16 inch in dimension. The 3/8 inch square stock was machine steel, and the remaining stock was mild steel, with the exception of 3/8 inch round which was wrought iron.

It was found necessary to use 110 volts A. C. primary voltage when welding stock up to and including 1/4 of an inch in diameter. A pressure of 220 volts could not be used on this small stock, because of the fact that the current which flowed under these conditions was so great as to burn the metal before the operator had sufficient time to make the weld. On the remaining sizes of test

pieces 220 volts A. C. was impressed upon the primary coil of the transformer, and was found to work very satisfactorily.

Test pieces 5/8 inches in diameter were placed in the machine and the circuit closed, but it was not possible to obtain a welding heat. This was due to the fact that the welding transformer had reached its overload capacity, and because of radiation of heat from the test pieces and the secondary coil of the transformer, the current was not of a sufficient value to bring the metal to a welding heat.

Most of the welds were made with the ends of the test pieces flat. However, a few welds were made from each size of stock with the ends conical. In making these welds the heating begins at the interior of the metal and comes outward. As pressure is exerted, the molten or burnt metal is forced out forming a burr at the joint. In nearly every case, the joint was slightly larger than stock, making a bulged weld.

TESTING OF THE WELDS

The purpose of testing the specimens after welding was to determine the efficiency of the weld. The specimens were tested for ultimate tensile strength in a Riehle Testing Machine. Ultimate tensile strength refers to the maximum stress which the specimen will stand. In the poorer welds the point of breaking, or rupture point of the specimens, was the ultimate strength of the welds, but in those which broke outside the weld, the ultimate strength of the weld was greater than the ultimate strength of the material. Such welds had an efficiency of more than 100 percent.

The specimens were first tested without turning down the

bulged joint to the original diameter of the stock. After reducing the area of the joint to that of the original stock, those specimens that broke outside of the joint were again tested and in each case, with the exception of one, again broke outside of the weld. The ultimate stress that caused this weld to rupture was approximately equal to the ultimate strength of the original stock; hence the efficiency of the weld was 100 percent.

The efficiencies of those specimens that broke in the welds were determined from the ultimate strength of the material before welding, and the ultimate strength of the specimen. The efficiency of the weld was not materially altered by the increase of cross-section, due to the metal forced out from the interior of the joint, because this metal was burned.

The first set of welds that were made and tested were found to be low in efficiency. In order to obtain better results it was necessary to weld another set of specimens, applying the current for a longer time. The data for the first set of welds is found in Tables number 2 to number 9 inclusive, and that for the second set of welds in Tables number 10 to 15 inclusive.

METHOD OF COMPUTING RESULTS

Ultimate strength, as referred to in the experiments, means the maximum strength that the specimen will withstand in a tension test. The efficiency of the welds, therefore, is the ratio of the ultimate strength of the specimen after welding, to the ultimate strength of the material, expressed in percent. For example, by referring to specimen number 2 in Table 2, it is seen that the ultimate strength of the weld is 2,080 pounds, and the ultimate

strength of the material is 2600 pounds. Therefore, the efficiency of the weld is $\frac{2,080}{2,600}$ x 100% = 80%. It is not necessary to reduce the values of ultimate strengths in pounds to ultimate strengths in pounds per square inch in computing the efficiency of the welds, since the cross-section area of the stock is practically the same in both cases.

In computing the power used in making the welds, the losses in the transformer were neglected since they are small in comparison to the power used. However, in computing the cost of power for welding, it is necessary to charge the transformer losses to the weld, since these losses are inherent with this process. Referring to specimen number 2 in Table 2, it is seen that the power consumed in making the weld is .0036 kilo-watt hours. For welding purposes it was assumed that power could be obtained for five cents per kilo-watt hour. Hence, the cost of power for making the weld is .0036 times 5 which is .018 cents. This does not include the wages of labor nor cost of material.

Since the ratio of primary to secondary turns is 56 to 1, the primary current was reduced to secondary current by multiplying by 56. In so doing, the magnetizing current which is very small in comparison to the primary current, was neglected. From this calculation, the value of current used in making the weld was obtained.

Tables of results were made, showing the data obtained during the test, and the computed data. These tables show the efficiency of each weld that was made, the power consumed, and the cost of the power.

TABLE 2.

Mild Steel - - - 3/16 Inch Diameter.

No. of specimen	1	2	3	4	5	6	7
Time in seconds	17	11	11	14	11	8.5	11
Aver. Current in Secondary-Amps.	4705	560.1	593	502	593	605	548.5
Power in K.W. Hours	.00443	.0036	.0035	.00368	.00302	.00301	.0030
Ult. Tensile Strength of Specimen in Pounds	2390	2080	2000	2180	1260	1520	1630
Ult. Tensile Strength of Material in Pounds	2600	2600	2660	2600	2600	2600	2600
Efficiency of Weld in Percent.	100	80	77	84	48.5	58.5	63.5
Cost of Welds-Cents	.0222	.018	.0175	.0184	.0152	.0151	.015
Broke	1 in. from W*	W	W	W	W	W	W
Voltage used	110		110	110	110	110	110

* W refers to the weld, hence W in the table means that the specimen broke in the weld or at a distance from it according to the context.

TABLE 3.

Mild Steel - 1/4 Inch Diameter.

No. of Specimen	1	2	3	4	5	6	7
Time in Seconds	45	50	35	50	28	22	37
Aver. Current in Secondary-Amps.	558	491	523	511	609	614	573
Power in K. W. Hours	.01345	.01422	.00987	.0139	.0102	.0075	.0118
Ult. Tensile Strength of Specimen in Pounds	1640	1640	2970	3390	2815	3080	3040
Ult. Tensile Strength of Material in Pounds	3070	3070	3070	3070	3070	3070	3070
Efficiency of Weld in Percent.	53.5	53.5	97	100	91.5	100	99
Cost of Welds-Cents	.672	.0712	.0493	.0695	.0510	.0375	.0590
Broke	W	W	W	W	1-1/2 in. from W	1-1/2 in. from W	W
Voltage used	110	110	110	110	110	110	110

TABLE 4.

Mild Steel - 1/4 Inch by 1/4 Inch.

No. of Specimen	1	2	3	4	5	6**	7**
Time in Seconds	33	31	33	40	36	30	29
Aver. Current in Secondary-Amps.	651	694.5	650	650	685	725	711
Power in K. W. Hours	.0119	.0123	.0123	.0123	.0135	.0115	.0117
Ult. Tensile Strength of Specimen in Pounds	2990	3990	3460	3910	3960	4000	3965
Ult. Tensile Strength of Material in Pounds	4000	4000	4000	4000	4000	4000	4000
Efficiency of Weld in Percent	73.5	100	86.5	98	99.15	100	99.2
Cost of Welds-Cents	.0595	.0615	.0615	.0615	.0675	.0575	.0585
Broke	W	2-1/2 in. from W	W	W	5 in. from W	3 in. from W	4 in. from W
Voltage used	110	110	110	110	110	110	110

** This refers to conical ends and when found after a number in the table signifies that the specimen referred to had conical ends before welding.

TABLE 5.

Mild Steel - 3/8 Inch Diameter.

No. of Specimen	1	2	3	4	5	6**	7**
Time in Seconds	13	11	10	10	11	10.5	10.5
Aver. Current in Secondary-Amps.	1761	1928	1849	1941	1780	1765	1720
Power in K.W. Hours	.0216	.0223	.0213	.0206	.0206	.0207	.0200
Ult. Tensile Strength of Specimen in Pounds	7080	3900	8130	6280	3350	6910	6860
Ult. Tensile Strength of Material in Pounds	7525	7525	7525	7525	7525	7525	7525
Efficiency of Weld in Per-cent.	94	51.8	100	83.4	45.4	100	91.5
Cost of Welds-Cents	.108	.1115	.1065	.1030	.1030	.1035	.1000
Broke	W	W	4 in. from W	W	W	5 in. from W	W
Voltage used	220	220	220	220	220	220	220

TABLE 6.

Wrought Iron - 3/8 Inch Diameter.

No. of Specimen	1	2	3	4	5**	6**	7
Time in Seconds	10	13	12	11	11	11	11
Aver. Current in Secondary-Amps.	1805	1861	1867.5	1772	1849	1810	1867.5
Power in K. W. Hours	.0213	.0218	.0237	.021	.0202	.0209	.0207
Ult. Tensile Strength of Specimen in Pounds	3420	4420	4900	3820	4920	3400	2980
Ult. Tensile Strength of Material in Pounds	4900	4900	4900	4900	4900	4900	4900
Efficiency of Weld in Percent.	70	90	100	78	100	69.5	61
Cost of Weld-Cents	.1065	.1090	.1185	.1050	.1010	.1045	.1035
Broke	W	W	3 in. from W	W	W	W	W
Voltage used	220	220	220	220	220	220	220

TABLE 7.

Machine Steel - 3/8 Inch by 3/8 Inch.

No. of Specimen	1	2	3	4	5	6**	7**
Time in Seconds	15	15	15	15	15	13	14.5
Aver. Current in Secondary-Amps.	2040	2010	1955	2090	1975	2145	1875
Power in K.W. Hours	.0300	.0312	.0315	.0320	.0322	.0299	.0298
Ult. Tensile Strength of Specimen in Pounds	7180	6900	6520	6770	7730	9610	9320
Ult. Tensile Strength of Material in Pounds	12760	12760	12760	12760	12760	12760	12760
Efficiency of Weld in Percent.	56.5	54	51	53	60.5	75.2	73
Cost of Welds-Cents	.15	.156	.1575	.1600	.1610	.1495	.1490
Broke	W	W	W	W	W	W	W
Voltage used	220	220	220	220	220	220	220

TABLE 8.

Mild Steel - 1/2 Inch Diameter.

No. of Specimen	1	2	3	4	5**	6**	7
Time in Seconds	40	35	45	43	37	35	37
Aver. Current in Secondary-Amps.	1820	1907	1595	1695	1785	1835	1766
Power in K. W. Hours	.077	.068	.0764	.0795	.0700	.0695	.0715
Ult. Tensile Strength of Specimen in Pounds	8740	9310	8410	8100	9850	9620	7530
Ult. Tensile Strength of Material in Pounds	12400	12400	12400	12400	12400	12400	12400
Efficiency of Weld in Percent.	70.5	75.0	68	65.4	79.5	77.5	61
Cost of Welds-Cents	.3855	.34	.382	.398	.35	.349	.358
Broke	W	W	W	W	W	W	W
Voltage used	220	220	220	220	220	220	220

TABLE 9.

Mild Steel - 7/16 Inch by 7/16 Inch.

No. of Specimen	1	2	3	4**	5	6	7**
Time in Seconds	30	34	45	36	44	39	37
Aver. Current in Secondary-Amps.	2065	1920	1800	1850	1732	1829	1844
Power in K. W. Hours	.0625	.0677	.084	.0677	.077	.0765	.0704
Ult. Tensile Strength of Specimen in Pounds	6320	9650	8370	7450	11.030	9120	8060
Ult. Tensile Strength of Material in Pounds	11720	11720	11720	11720	11720	11720	11720
Efficiency of Weld in Percent	54	82.2	71.5	63.5	94	77.8	69
Cost of Welds-Cents	.3125	.3385	.4200	.3385	.3885	.383	.352
Broke	W	W	W	W	W	W	W
Voltage used	220	220	220	220	220	220	220

TABLE 10.

Mild Steel - 3/8 Inch Diameter.

Number of Specimen	1	2	3	4
Time in Seconds	19	16	14	13
Average Current in Secondary - Amperes	1595	1765	1830	1850
Power in K. W. Hours	.313	.031	.0267	.024
Ultimate Tensile Strength of Specimen in Pounds	5100	5100	4800	3840
Ultimate Tensile Strength of Material in Pounds	5100	5100	5100	5100
Efficiency of Weld in Percent	100	100	94.2	75.2
Cost of Welds - Cents	.1565	.155	.1335	.1200
Broke	4 in. from W	4 in. from W	W	W
Voltage used	220	220	220	220

TABLE 11.

Wrought Iron - 3/8 Inch in Diameter.

Number of Specimen	1	2	3	4
Time in Seconds	13	16	16	20
Average Current in Secondary - Amperes	1710	1771	1720	1490
Power in K. W. Hours	.0275	.0304	.0280	.0320
Ultimate Tensile Strength of Specimen in Pounds	6200	7040	7080	7050
Ultimate Tensile Strength of Material in Pounds	7080	7080	7080	7080
Efficiency of Weld in Percent	87.5	100	100	100
Cost of Welds - Cents	.1375	.1520	1400	1600
Broke	W	4 in. from W	4 in. from W	5 in. from W
Voltage used	220	220	220	220

TABLE 12

Machine Steel - 3/8 Inch by 3/8 Inch.

Number of Specimen	1	2	3	4
Time in Seconds	25	24	24	
Average Current in Secondary - Amperes	1820	1785	1820	
Power in K. W. Hours	.0422	.0432	.0410	
Ultimate Tensile Strength of Specimen in Pounds	9100	10,100	10,000	
Ultimate Tensile Strength of Material in Pounds	12450	12450	12450	
Efficiency of Weld in Percent	73.2	81.1	80.2	
Cost of Welds-Cents	.2110	.2160	.2050	
Broke	W	W	1 in. from W	
Voltage used	220	220	220	

TABLE 13.

Mild Steel - 7/16 Inch by 7/16 Inch.

Number of Specimen	1	2	3	4
Time in Seconds	42	42	43	62
Average Current in Secondary - Amperes	1720	1775	1805	1715
Power in K. W. Hours	.0620	.0776	.0717	.1060
Ultimate Tensile Strength of Specimen in Pounds	10330	8470	11940	10740
Ultimate Tensile Strength of Material in Pounds	12130	12130	12130	12130
Efficiency of Weld in Percent	85.2	70	98.5	88.3
Cost of Welds-Cents	.3100	.3880	.3580	.5300
Broke	W	W	W	W
Voltage used	220	220	220	220

TABLE 14.

Mild Steel - 1/2 Inch in Diameter.

Number of Specimen	1	2	3
Time in Seconds	49	49	47
Average Current in Secondary - Amperes	1762	1774	1890
Power in K. W. Hours	.0875	.0893	.0907
Ultimate Tensile Strength of Specimen in Pounds	11450	10520	11200
Ultimate Tensile Strength of Material in Pounds	12450	12450	12450
Efficiency of Weld in Percent	92	84.5	90
Cost of Welds - Cents	.4350	.4470	.4530
Broke	W	W	W
Voltage used	220	220	220

TABLE 15.

Mild Steel - 1/4 Inch by 3/4 Inch.

Number of Specimen	1	2	3	4
Time in Seconds	62	130	93	60
Average Current in Secondary - Amperes	1585	1375	1387	1675
Power in K. W. Hours	.0937	.1720	.1180	.1232
Ultimate Tensile Strength of Specimen in Pounds	9900	6940	7700	9610
Ultimate Tensile Strength of Material in Pounds	11030	11030	11030	11030
Efficiency of Weld in Percent	89.6	63	69.8	87.2
Cost of Welds - Cents	.4770	.8600	.5900	.6160
Broke	W	W	W	W
Voltage used	220	220	220	220

TABLE 16.

Size of Specimen in Dia.	Time in Seconds.	Aver. Current in Secondary. Amperes.	Power Consumed in Watt Hours
	0	560	
	5	504	
3/16	10	437	4.43
Mild	15	426	
	17	426	
- - -	- - -	- - -	- - -
	0	672	
	10	560	
1/4	15	549	11.8
Mild	25	549	
	37	532	
- - -	- - -	- - -	- - -
	0	784	
	5	728	
	10	684	
	15	672	
1/4 Square	20	650	13.5
Mild	25	650	
	30	650	
	36	655	
- - -	- - -	- - -	- - -
	0	1850	
3/8 Mild	5	1763	21.6

TABLE 16. Continued.

Size of Specimen in Dia.	Time in Seconds.	Aver. Current in Secondary Amperes.	Power Consumed in Watt Hours
	10	1721	
	13	1736	
- - -	- - -	- - -	- - -
	0	2015	
	5	1850	
3/8 Wrought	10	7652	30.4
	16	1569	
- - -	- - -	- - -	- - -
	0	1960	
	5	1932	
	10	1850	
3/8 Square Machine Steel	15	1763	41.0
	20	1705	
	24	1680	
- - -	- - -	- - -	- - -
	0	1960	
	5	1875	
	10	1835	
	15	1815	
7/16 Square Mild	20	1776	71.7
	25	1750	
	30	1736	
	35	1736	
	43	1747	

TABLE 16 CONTINUED

Size of Specimen in Dia.	Time in Seconds.	Aver. Current in Secondary Amperes.	Power Consumed in Watt Hours
	0	2050	
	5	2040	
	10	2015	
	15	1960	
	20	1888	
1/2 Mild	25	1830	90.7
	30	1803	
	35	1776	
	40	1763	
	47	1755	

TABLE 17.

Size of Specimen Round	Material	Aver. Power Original Test	Aver. Power Second Test	Aver. Efficiency Original Test	Aver. Efficiency Second Test.	Aver. Cost for Power Original	Aver. Cost for Power Second Test.
Sq. In.		Watt Hours		Percent		Cents.	
.0276	Mild Steel	3.46	--	73	--	.0173	--
.0491	" "	11.56	--	84.8	--	.0578	--
.1103	" "	21.01	28.25	80.8	92.3	.1050	.1412
.1103	Wrought Iron	21.40	29.50	81.2	96.9	.1072	.1475
.1965	Mild Steel	73.15	89.16	71.0	88.8	.3657	.4458
Square .0625	Mild Steel	12.93	--	93.9	--	.0646	--
.1405	Machine Steel	31.04	42.13	60.5	78.1	.1552	.2106
.1915	Mild Steel	72.54	79.32	73.1	85.5	.3627	.3966

CURVES

Curves were plotted showing the variation of current with time of making weld, for various sizes of material, and for an impressed voltage of 110 and 220 volts. These curves are shown on plates number 1 and number 2. In every case the curves show that the current decreased with increase of time, due to the fact that the heating of the material increased its resistance.

The curves on plate number 3 show the variation of average power consumed in making the weld, with the cross-sectional area of the material. The lower curve was plotted from data in Table number 17, of specimens having low efficiencies, compiled from average values in Tables number 2 to 9 inclusive. The upper curve was plotted from data in Table number 17, of specimens having high efficiencies, taken from average values in Tables number 10 to number 14 inclusive. A comparison of these curves shows that more power was consumed in making welds of higher efficiency.

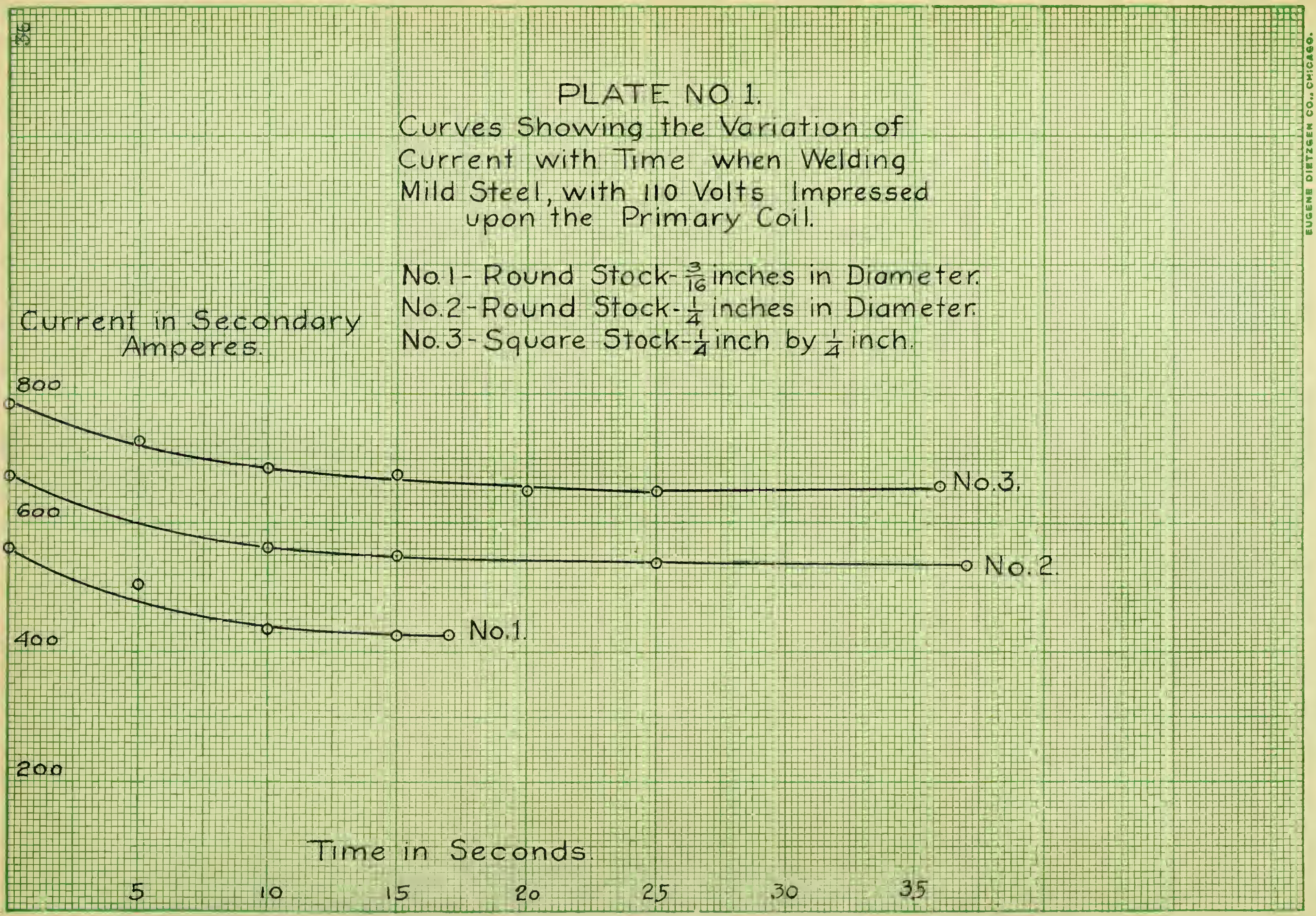
PLATE NO 1.
Curves Showing the Variation of Current with Time when Welding Mild Steel, with 110 Volts Impressed upon the Primary Coil.
No.1 - Round Stock - 3/16 inches in Diameter.
No.2 - Round Stock - 1/4 inches in Diameter.
No.3 - Square Stock - 1/4 inch by 1/4 inch.
Current in Secondary Amperes.
800
600
400
200
No.3.
No. 2.
No.1.
Time in Seconds.
5
10
15
20
25
30
35

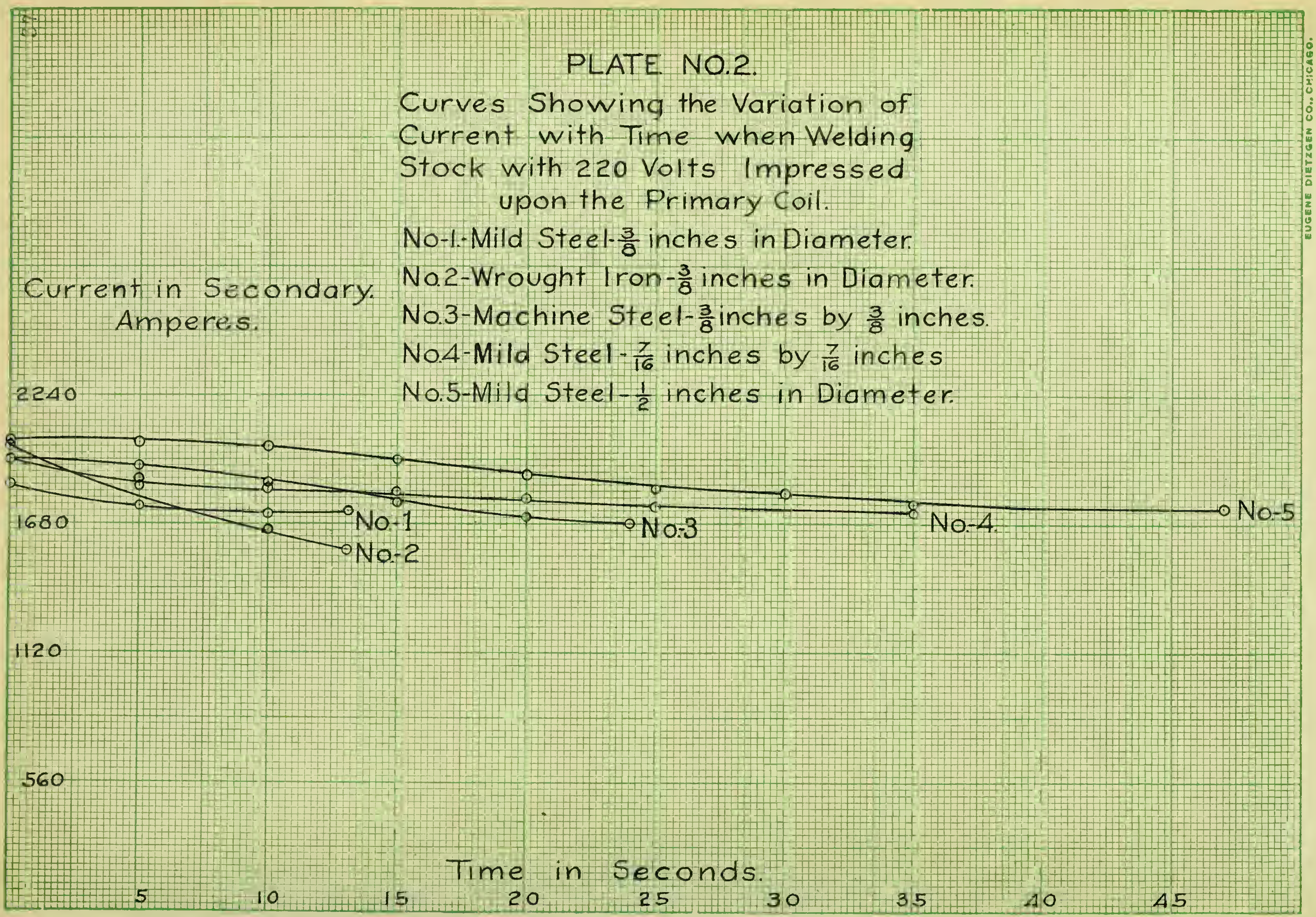

PLATE NO.2.
Curves Showing the Variation of Current with Time when Welding Stock with 220 Volts Impressed upon the Primary Coil.
No-1.-Mild Steel-3/8 inches in Diameter.
No.2-Wrought Iron-3/8 inches in Diameter.
No.3-Machine Steel-3/8 inches by 3/8 inches.
No.4-Mild Steel-7/16 inches by 7/16 inches
No.5-Mild Steel-1/2 inches in Diameter.
Current in Secondary. Amperes.
2240
1680
1120
560
No-1
No-2
No-3
No-4.
No-5
Time in Seconds.
5
10
15
20
25
30
35
40
45

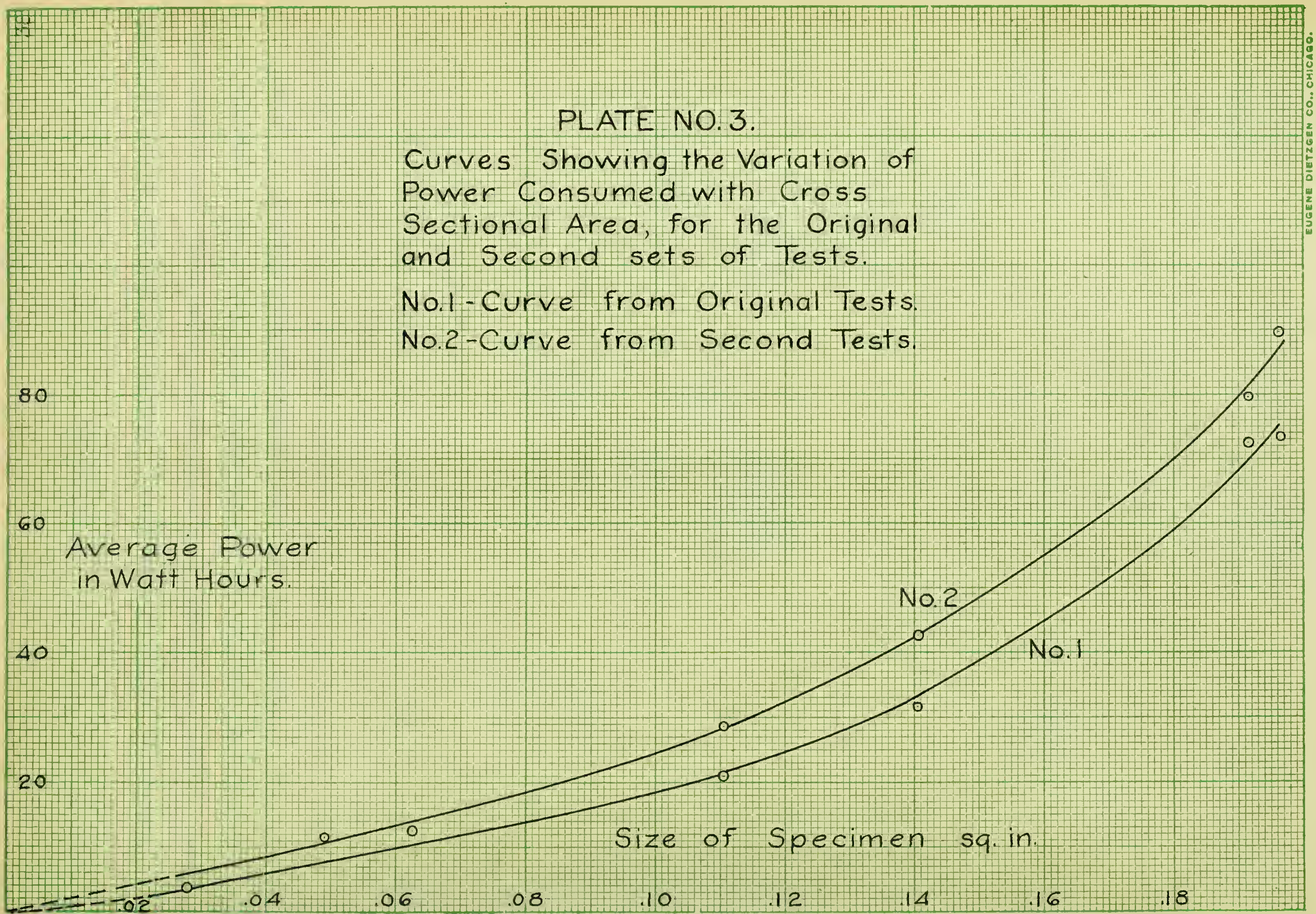
PLATE NO. 3.
Curves Showing the Variation of Power Consumed with Cross Sectional Area, for the Original and Second sets of Tests.
No.1 - Curve from Original Tests.
No.2 - Curve from Second Tests.
Average Power in Watt Hours.
Size of Specimen sq. in.
No. 2
No. 1
80
60
40
20
.02
.04
.06
.08
.10
.12
.14
.16
.18
EUGENE DIETZGEN CO., CHICAGO.

CONCLUSIONS

From an investigation of the results of all the tests of welds made by the resistance method of electric welding, it is seen that the welds having the best efficiency were made with a smaller value of current than was used in making the welds of the same size having a poorer efficiency, but the current in the first case was applied for a greater length of time. This was found true for lengths of time up to a critical point, after which further application of the current burned the metal at the joint, thereby decreasing the efficiency of the weld.

The increase of cross-sectional area at the joint, due to pressure applied does not effect the efficiency of the poorer welds, because this increased area was composed of burned metal, forced out from the center of the weld, as shown by an investigation of the ends of the broken specimens. A study of the high efficiency welds shows that the joints in most cases were slightly bulged, but the material in the joint was not burned; therefore, a better weld was obtained.

From these experiments, the results show that the average efficiency of welds made from stock with conical ends is practically the same as the average efficiency of welds made from stock with flat ends; therefore, in small stock such as was used in these tests, there is no advantage, as far as efficiency is concerned, in making welds from stock with conical ends. However, when welds are to be made from larger stock it is reasonable to believe that it is an advantage to have conical ends, due to the fact that the metal at the center will reach a welding heat an appreciable length of time before that at the surface.

In such a case, if conical ends were used, the molten metal at the center of the weld would be forced out to the edge as pressure is applied, allowing time for the outside surface to reach a welding temperature.

The results also show that the power required to weld wrought iron is approximately five percent greater than that required to weld mild steel of the same size, the time of producing the weld being approximately the same in both cases. Machine steel was successfully welded, but since no other material of the same size was welded, it is not possible to make a comparison of power required, and time of producing the weld.

From the curves on curve sheet number 3, it is seen that the power required to weld round and square stock is about the same. This fact is true for small specimens such as was welded in this test. But for larger stock, the power required to weld square material will probably be greater than that required for round material of the same cross-sectional area, because of the increase in radiating surface. This difference of power is not shown in the results of the tests since the increase of radiating surface for square material is very small in comparison to the radiating surface for round material of the same cross-sectional area, on small stock. These curves also show that the power consumed in welding material of different sizes does not vary directly with the cross-sectional area, but varies as some power of the cross-sectional area greater than one.

The average efficiencies of all the welds made in the original and second tests were found to be 77.4 percent, and 88.3

percent respectively. This would indicate, that with more experience on the part of, the operator, welds of still higher efficiencies could be made.

The scope of this investigation was limited by the small capacity of the welding machine, since it was impossible to weld stock larger than one-half of an inch in diameter.